US009281155B2

(12) **United States Patent**
**Ueda et al.**

(10) **Patent No.: US 9,281,155 B2**
(45) **Date of Patent: Mar. 8, 2016**

(54) **RADIATION GENERATING APPARATUS AND RADIATION IMAGING APPARATUS**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 183 days.

(21) Appl. No.: **13/884,339**

(22) PCT Filed: **Nov. 8, 2011**

(86) PCT No.: **PCT/JP2011/076134**

§ 371 (c)(1), (2), (4) Date: **May 9, 2013**

(87) PCT Pub. No.: **WO2012/077463**

PCT Pub. Date: **Jun. 14, 2012**

(65) **Prior Publication Data**

US 2013/0230143 A1 Sep. 5, 2013

(30) **Foreign Application Priority Data**

Dec. 10, 2010 (JP) ................................ 2010-275620

(51) **Int. Cl.**
***H01J 35/02*** (2006.01)
***H01J 35/18*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ................ ***H01J 35/02*** (2013.01); ***H01J 35/18*** (2013.01); ***H05G 1/025*** (2013.01); ***H05G 1/04*** (2013.01); *H01J 2235/1204* (2013.01); *H01J 2235/186* (2013.01)

(58) **Field of Classification Search**
CPC .................... H01J 2235/186; H01J 2235/087; H01J 35/02; H01J 35/12; H01J 35/16; H01J 35/18; H01J 35/105; H01J 2235/1024; H05G 1/02; H05G 1/025; H05G 1/04
USPC .......................... 378/119, 121, 130, 141, 143
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,098,315 A * 11/1937 Sharp ............................ 378/141
3,867,637 A * 2/1975 Braun et al. ...................... 378/2
(Continued)

FOREIGN PATENT DOCUMENTS

JP H07-057668 3/1995
JP H07-260713 A 10/1995
(Continued)

OTHER PUBLICATIONS

Office Action issued on Mar. 26, 2014, in counterpart EPA 11793511.4.

(Continued)

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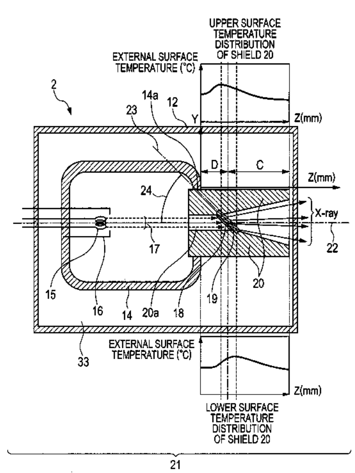
(57) **ABSTRACT**

A radiation generating apparatus has a radiation generating tube held in a holding container **12** and a cooling medium between the holding container and the radiation generating tube. The radiation generating tube includes an envelope with an aperture, an electron emitting source arranged in the envelope, a target arranged facing the source, for generating radiation responsive to irradiation with an electron beam emitted from the source, and a tubular shield for holding the target by an inner wall thereof and shielding part of the radiation emitted from the target. The shield is arranged to protrude outward of the envelope so that the target is positioned on an outer side of the aperture, and the cooling medium contacts at least a part of the shield.

**16 Claims, 4 Drawing Sheets**



(51) **Int. Cl.**

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|---|---|
| ***H05G 1/02*** | (2006.01) |
| ***H05G 1/04*** | (2006.01) |

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 4,400,824 | A * | 8/1983 | Shidara | 378/141 |
| 4,455,504 | A * | 6/1984 | Iversen | 313/30 |
| 5,629,969 | A | 5/1997 | Koshishiba | 378/138 |
| 8,139,716 | B2 | 3/2012 | Okunuki et al. | 378/122 |
| 8,472,585 | B2 | 6/2013 | Ogura et al. | |
| 2003/0021377 | A1 | 1/2003 | Turner et al. | 378/102 |
| 2004/0076260 | A1* | 4/2004 | Charles, Jr. et al. | 378/124 |
| 2007/0025516 | A1* | 2/2007 | Bard et al. | 378/138 |
| 2008/0089484 | A1* | 4/2008 | Reinhold | 378/138 |
| 2008/0232546 | A1* | 9/2008 | Stierstorfer | 378/70 |
| 2009/0086898 | A1* | 4/2009 | Richardson et al. | 378/45 |
| 2012/0307974 | A1 | 12/2012 | Yamazaki et al. | |
| 2012/0307978 | A1 | 12/2012 | Yamazaki et al. | |
| 2013/0016810 | A1 | 1/2013 | Tamura et al. | |
| 2013/0016811 | A1 | 1/2013 | Ueda et al. | |
| 2013/0016812 | A1 | 1/2013 | Yanagisawa et al. | |
| 2013/0034207 | A1 | 2/2013 | Aoki et al. | |
| 2013/0148781 | A1 | 6/2013 | Yamazaki et al. | |

FOREIGN PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| JP | H07-260713 | A | 10/1995 |
| JP | 2002-343290 | A | 11/2002 |
| JP | 2005-523558 | A | 8/2005 |
| JP | 2007-265981 | | 10/2007 |
| WO | WO 2006/105332 | | 10/2006 |

OTHER PUBLICATIONS

C. Jensen et al., "Improvements in Low Power, End-Window, Transmission-Target X-Ray Tubes", *Advances in X-Ray Analysis*, vol. 47, pp. 64-69 (2004).

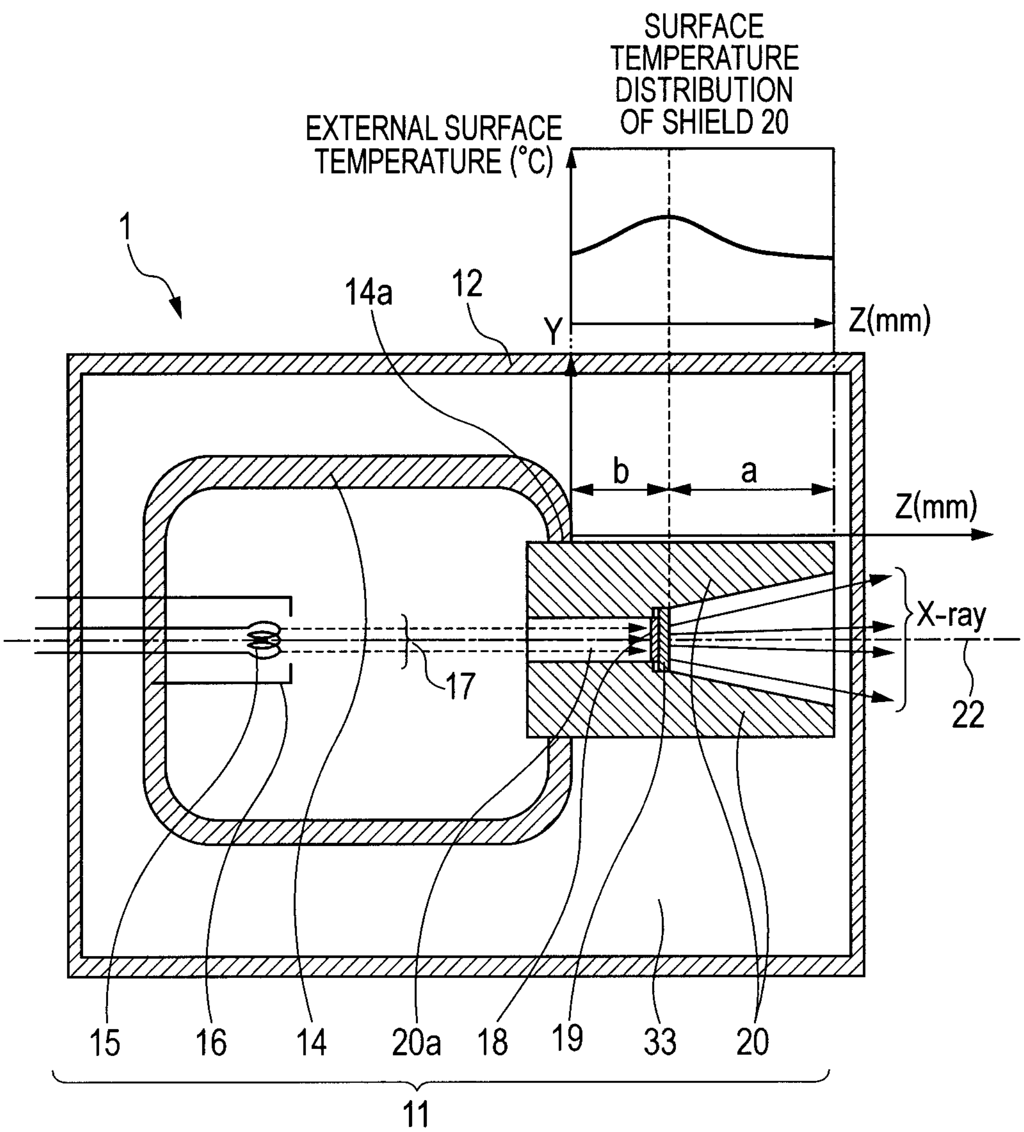
Office Action issued on Apr. 28, 2014 in counterpart Korean application 10-2013-7016456, with translation (see above).

Office Action issued in Japanese Patent Application 2010-275620 on Sep. 24, 2013, with partial translation.

Office Action issued on Feb. 28, 2015 in counterpart Chinese application 201180058649.3, with translation.

* cited by examiner

FIG. 1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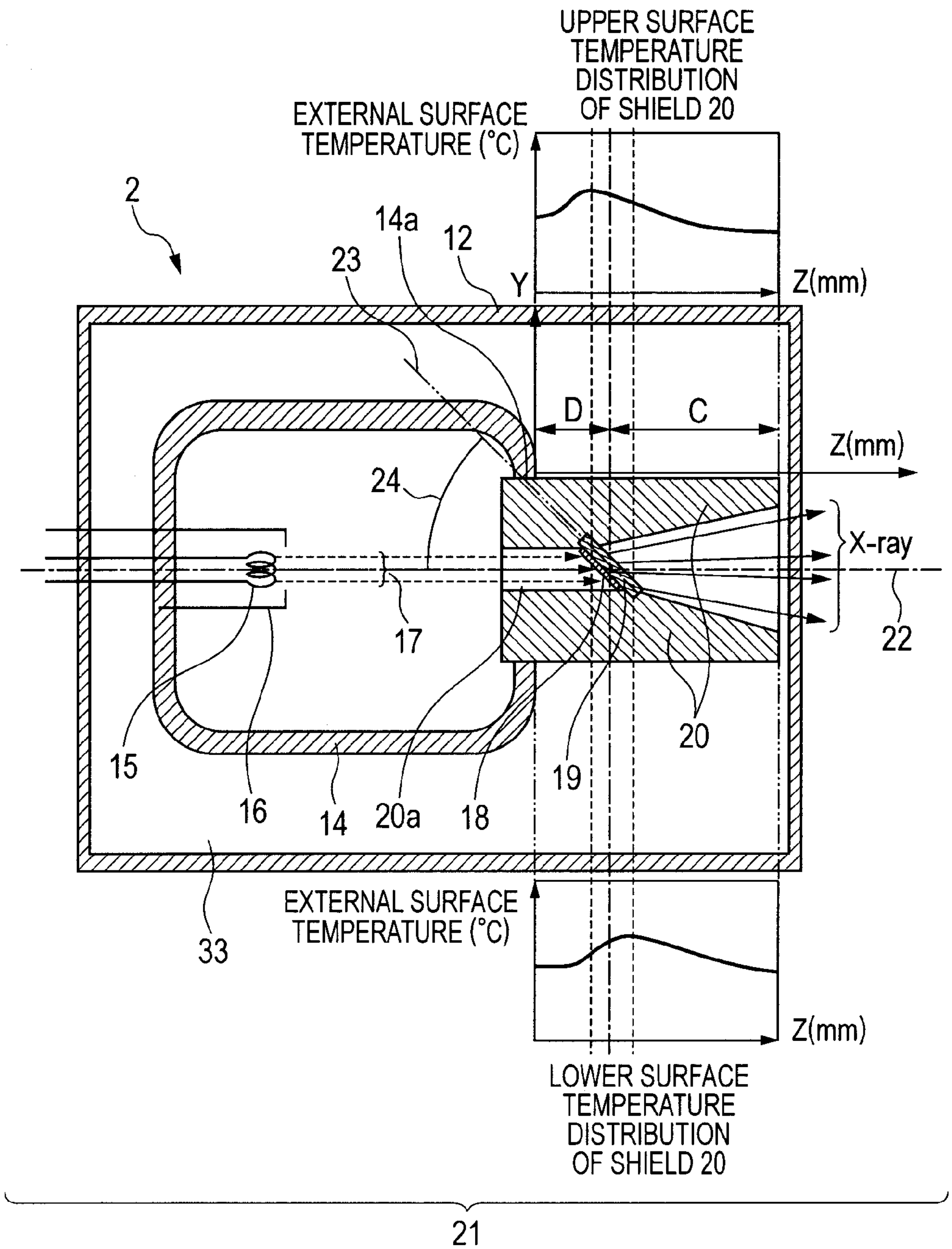
Z(mm)
Y
1
14a
12
b
a
Z(mm)
X-ray
17
22
15
16
14
20a
18
19
33
20
11

FIG. 2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14a
12
23
Y
Z(mm)
D
C
Z(mm)
24
X-ray
17
22
20
15
16
14
20a
18
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33
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Z(mm)
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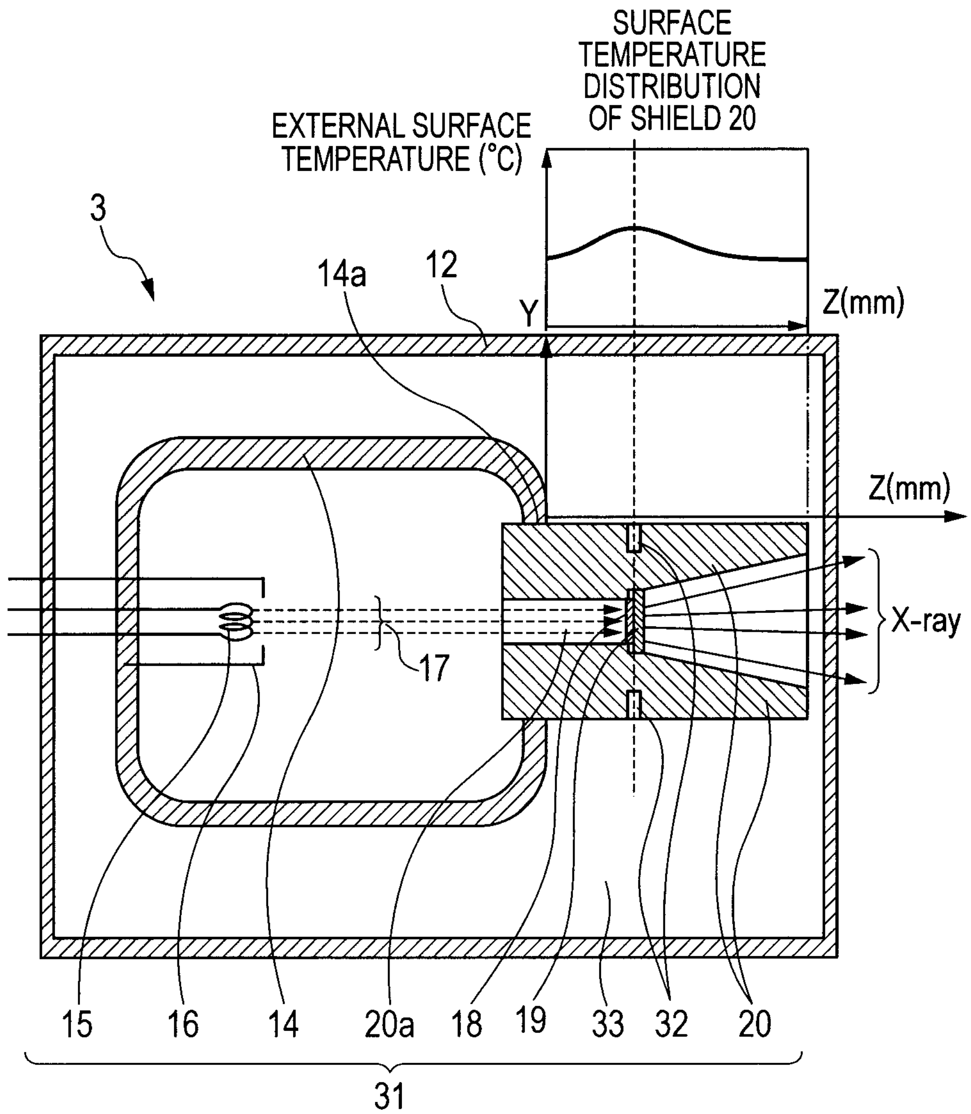
FIG. 3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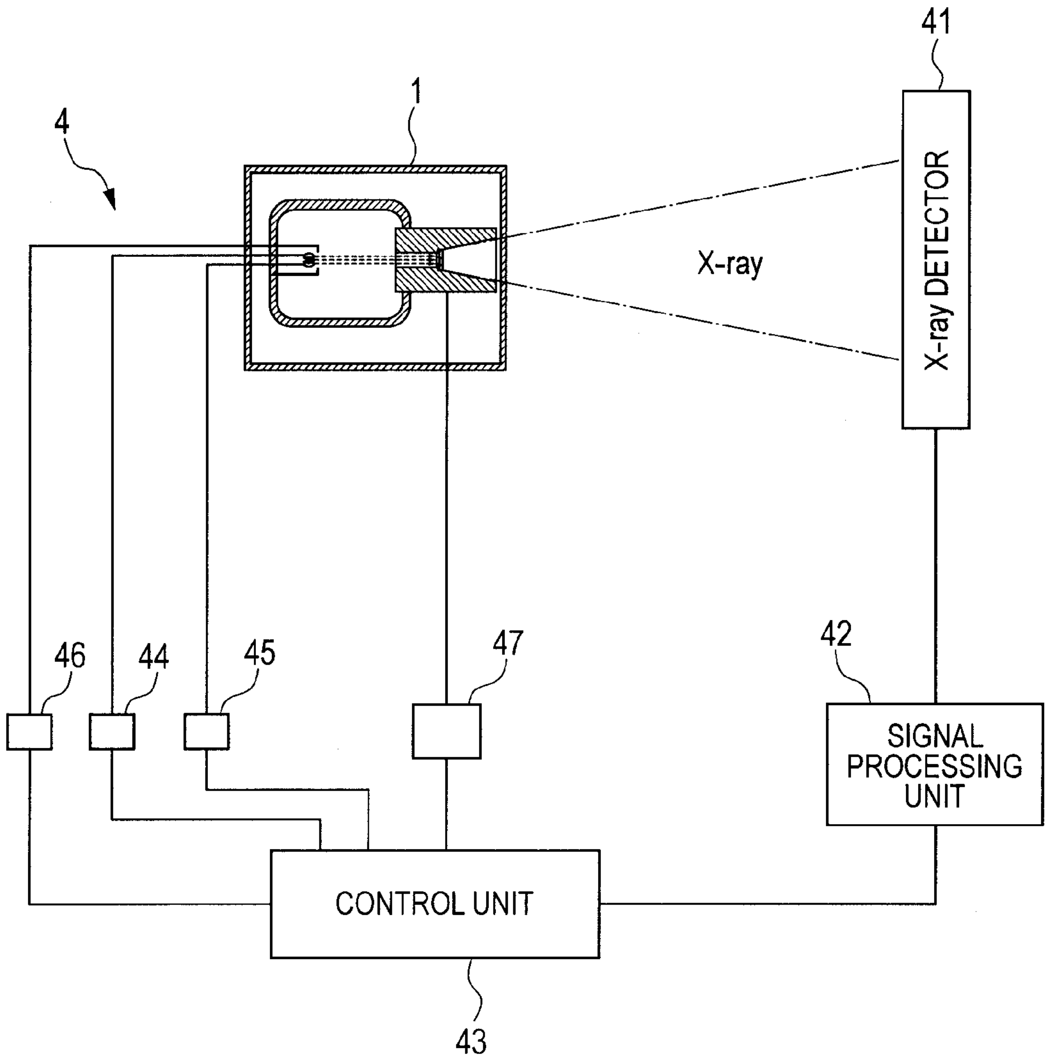
TEMPERATURE
DISTRIBUTION
OF SHIELD 20
EXTERNAL SURFACE
TEMPERATURE (°C)
3
14a
12
Y
Z(mm)
Z(mm)
17
X-ray
15
16
14
20a
18
19
33
32
20
31

FIG. 4


41
1
4
X-ray
X-ray DETECTOR
46
44
45
47
42
SIGNAL PROCESSING UNIT
CONTROL UNIT
43

# RADIATION GENERATING APPARATUS AND RADIATION IMAGING APPARATUS

## TECHNICAL FIELD

The present invention relates to a radiation generating apparatus including a holding container that is charged with a cooling medium and houses therein a transmission type radiation generating tube using an electron emitting source, and a radiation imaging apparatus including such radiation generating apparatus.

## BACKGROUND ART

In general, a radiation generating tube accelerates electrons emitted from an electron emitting source to high energies and irradiates a target including a metal, such as tungsten, with the high energies to generate radiations such as X-rays. The generated radiations are emitted in all directions. Therefore, in order to shield unnecessary radiations, a container is provided to house the radiation generating tube or the radiation generating tube is surrounded by a shield (radiation shielding member) such as one including lead to prevent external leakage of the unnecessary radiations. Thus, such radiation generating tube and such radiation generating apparatus that houses the radiation generating tube therein have a difficulty in size and weight reduction.

As a solution for this problem, Japanese Patent Application Laid-Open No. 2007-265981 discloses a method in which a shield is arranged on each of the radiation emission side and the electron entrance side of a target in a transmission type radiation generating tube to shield unnecessary radiations with a simple structure as well as providing reduction in size and weight of the apparatus.

However, in general, in such transmission type radiation generating tube to which a target, i.e., an anode is fixed, the target does not necessarily sufficiently radiates heat because of the effect of local heat generated in the target, resulting in difficulty in generation of high-energy radiation. Regarding the target's heat radiation, PTL 1 describes that the transmission type radiation generating tube described therein has a structure in which a target and a shield are joined to each other, thereby heat generated in the target being radiated as a result of being transferred to the shield, enabling suppression of an increase in temperature of the target.

## CITATION LIST

### Patent Literature

PTL 1: Japanese Patent Application Laid-Open No. 2007-265981

## SUMMARY OF INVENTION

### Technical Problem

However, in the transmission type radiation generating tube disclosed in PTL 1, the shield is arranged in a vacuum container, limiting a region of heat transfer from the shield to the outside of the vacuum container. Thus, the target does not necessarily sufficiently radiate heat, and therefore, there is a problem in providing both the capability of cooling the target and reduction in size and weight of the apparatus.

Therefore, an object of the present invention to provide a radiation generating apparatus capable of shielding unnecessary radiations and cooling a target with a simple structure as well as enabling size and weight reduction, and a radiation imaging apparatus including the same.

### Solution to Problem

In order to achieve the object, a radiation generating apparatus according to the present invention comprises: radiation generating apparatus comprising: a radiation generating tube; a holding container for holding inside thereof the radiation generating tube; and a cooling medium positioned between the holding container and the radiation generating tube, wherein the radiation generating tube has an envelope having an aperture, an electron emitting source arranged in the envelope, a target arranged in opposition to the electron emitting source, for generating a radiation responsive to an irradiation with an electron beam emitted from the electron source, and a shield member with tubular shape, for holding the target within an inner wall of the shield member, and for shielding a part of the radiation emitted from the target, the shield member protrudes toward an outside of the envelope so that the target is held at an outer side of the envelope beyond the aperture, and the cooling medium contacts at least a part of the shield member.

### Advantageous Effects of Invention

The present invention can provide a structure in which a large area is provided for radiating heat to the cooling medium **33** and a part having a highest temperature serves as a heat radiation surface. Consequently, heat of the target is transferred to the cooling medium **33** through the transmitting substrate and the shield, and thus, the beneficial advantageous effect of providing a radiation generating apparatus using a highly-reliable transmission type radiation generating tube that can suppress an increase in temperature of the transmitting substrate for enabling long-time driving for radiation generation is provided.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to a first embodiment, and a temperature distribution diagram at an external surface of a shield.

FIG. **2** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to a second embodiment, and a temperature distribution diagram at an external surface of a shield.

FIG. **3** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to a third embodiment, and a temperature distribution diagram at an external surface of a shield.

FIG. **4** is a schematic diagram of a radiation imaging apparatus according to a fourth embodiment.

## DESCRIPTION OF EMBODIMENTS

Hereinafter, embodiments of the present invention will be described with reference to the drawings; however, the present invention is not limited to these embodiments. Techniques known in the art or publicly known are applied to parts neither specifically illustrated in the drawings nor described in the specification.

First Embodiment

First, a radiation generating apparatus according to a first embodiment of the present invention will be described with reference to FIG. **1**. FIG. **1** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to the present embodiment, and a temperature distribution diagram at an external surface of a shield. The schematic cross-sectional diagram in FIG. **1** indicates a Z-Y cross-section with a direction of a center line of an electron flux (electron flux center line **22**) as a Z-axis direction.

As illustrated in FIG. **1**, a radiation generating apparatus **1** according to the present embodiment includes a transmission type radiation generating tube **11**, and the transmission type radiation generating tube **11** is housed inside a holding container **12**. The rest of the space inside the holding container **12** except the space in which the transmission type radiation generating tube **11** is housed is charged with a cooling medium **33**.

The holding container **12** is a metal container defined by metals plates to form a box shape. The metal included in the holding container **12** has electric conductivity, and may be, e.g., iron, stainless steel, lead, brass or copper, and provides a structure that can support the weight of the container. A part of the holding container **12** is provided with a non-illustrated inlet for injecting the cooling medium **33** into the holding container **12**. Since the temperature of the cooling medium **33** increases when the transmission type radiation generating tube **11** is driven, a non-illustrated pressure adjustment port using an elastic member may be provided at a part of the holding container **12** as necessary in order to avoid an increase in internal pressure of the holding container **12** when the cooling medium **33** expands.

The cooling medium **33** may be any liquid having an electrical insulating property, and desirably causing less alteration by heat and having a high cooling capability and a low viscosity, and for example, may be an electrical insulating oil such as a silicone oil or a fluorine series oil, or a fluorine series inactive liquid.

The transmission type radiation generating tube **11** includes a cylindrical envelope **14** including a circular aperture portion **14***a*, an electron emitting source **15**, a control electrode **16**, a transmitting substrate **19**, a target **18** and a shield **20**.

The envelope **14** includes a high electrical insulating material having a high heat resistance as well as capability of maintaining a high vacuum. Here, the high electrical insulating material may be, for example, alumina or heat resistance glass. As described later, the inside of the envelope **14** is maintained at a predetermined degree of vacuum.

Inside the envelope **14**, the electron emitting source **15** is arranged so as to face the aperture portion **14***a* of the envelope **14**. Although the electron emitting source **15** in the present embodiment is, for example, a filament, the electron emitting source **15** may be another electron emitting source such as an impregnation-type cathode or a field emission-type component. In general, in order to maintain a degree of vacuum equal to or lower than $1\times10^{-4}$ Pa, which enables driving of the electron emitting source **15**, a non-illustrated getter, NEG or small ion pump for absorbing a gas emitted in driving the transmission type radiation generating tube **11** is mounted inside the envelope **14**.



A control electrode **16** is arranged around the electron emitting source **15**. Thermal electrons emitted from the electron emitting source **15** form an electron flux **17**, which includes electrons accelerated toward the target **18**, by means of a potential of the control electrode **16**. On/off control of the electron flux **17** is performed by control of a voltage of the control electrode **16**. The control electrode **16** includes a material such as, for example, stainless steel, molybdenum or iron. The target **18** has a positive potential relative to the electron emitting source **15**, and thus, the electron flux **17** is attracted to and collides with the target **18**, resulting in generation of radiations. The radiation generating apparatus **1** according to the present embodiment is configured as an X-ray generating apparatus in which the target **18** is irradiated with the electron flux **17** to generate X-rays as radiations.

It should be noted that a lens electrode can be provided ahead of the control electrode **16** in a direction of the electron irradiation for a diameter of the electron flux to be further converged.

In the aperture portion **14***a* of the envelope **14**, a shield **20** is provided so as to protrude toward the outside of the envelope **14**, a portion of joint between the envelope **14** and the shield **20** has a sealed structure. The shield **20** has a cylindrical shape, and a passage **20***a* that communicates with the aperture portion **14***a* of the envelope **14**. The shield **20** may include a metal having a high X-ray absorbing capability such as tungsten, molybdenum, oxygen-free copper or lead.

A transmitting substrate **19** that transmits radiations is provided at a position in the passage **20***a* in the shield **20**. The target **18** is arranged on a surface on the electron emitting source side of the transmitting substrate **19**. The transmitting substrate **19** has a function that absorbs X-rays in unwanted directions, which are emitted from the target **18**, and a function as a plate for diffusing heat of the target **18**. The transmitting substrate **19** includes a material that is high in heat conductivity and low in X-ray attenuation quantity and has a plate-like shape, and, e.g., SiC, diamond, or thin-film oxygen-free copper is suitable for the material. The transmitting substrate **19** is joined to the passage **20***a* of the shield **20** by means of, e.g., silver brazing. An arrangement of the transmitting substrate **19** in the passage **20***a* of the shield **20** will be described later.

When generating X-rays, for example, tungsten, molybdenum, copper or gold is used for the target **18**. The target **18** includes a metal thin film, and is provided on the surface on the electron emitting source side of the transmitting substrate **19**. When an X-ray radiograph of a human body is taken, the target **18** has a potential around +30 to 150 KV higher than a potential of the electron emitting source **15**. Such potential difference is an accelerating potential difference necessary for the X-rays emitted from the target **18** to penetrate the human body to effectively contribute to the radiography.

When tungsten is used, the target **18** has a film thickness of, for example, from around 3 to 15 μm. In the case of a film thickness of 3 μm, a predetermined X-ray generation amount can be obtained by applying a voltage making the potential of the electrons of the target **18** be +30 KV higher than the potential of the electron emitting source **15**. Also, in the case of a film thickness of 15 μm, a predetermined X-ray generation amount can be obtained by applying a voltage making the potential of the target **18** be around +150 KV higher than the potential of the electron emitting source **15**.

In the passage **20***a* of the shield **20**, the transmitting substrate **19** is arranged at a position on the outer side relative to an external wall surface of the envelope **14**. A part of the passage **20***a* of the shield **20** up to a position where the transmitting substrate **19** is arranged is a cylindrical hole, while a part of the passage **20***a* on the side of the transmitting substrate **19** opposite to the electron emitting source has a shape with a gradually increasing an internal diameter. In the present embodiment, the transmitting substrate **19** and the target **18** provided in the passage **20***a* of the shield **20** are arranged at a position on the outer side relative to the external wall surface of the envelope **14** in their entireties.

Since the transmitting substrate **19** is joined to a position in the passage **20***a* of the shield **20**, and thus, the vacuum on the envelope **14** side relative to the transmitting substrate **19** is maintained. Furthermore, the cooling medium **33** charged inside the holding container **12** enters a part of the passage **20***a* of the shield **20** on the outer side relative to the transmitting substrate and contacts the transmitting substrate **19**.

In other words, in the present embodiment, the cooling medium **33** contacts the transmitting substrate **19**, a major part of an external surface of the shield **20** and an internal surface of the passage **20***a* on the outer side relative to the transmitting substrate. Since the transmitting substrate **19** is joined to the passage **20***a* of the shield **20**, and thus, when X-rays are generated as a result of the electron flux **17** colliding with the target **18**, heat generated in the target **18** is transferred to the cooling medium **33** through the transmitting substrate **19** and the shield **20**.

For achieving the aforementioned heat transfer, it is only necessary that at least a part of the transmitting substrate **19** be arranged at a position on the outer side relative to the external wall surface of the envelope **14**. Furthermore, the target-mounting surface of the transmitting substrate **19** has a high temperature because of the contact with the target **18**, and thus, the target-mounting surface can be positioned on the outer side relative to the external wall surface of the envelope **14**. Furthermore, it is only necessary that the cooling medium **33** contact at least a part of the shield **20**.

Next, an operation when the radiation generating apparatus **1** according to the present embodiment is driven will be described with reference to the temperature distribution diagram in the upper part of FIG. **1**. When the transmission type radiation generating tube **11** in the radiation generating apparatus **1** according to the present embodiment is driven, a temperature distribution occurs on the external surface of the shield **20**. As illustrated in the temperature distribution diagram in FIG. **1**, a temperature distribution exhibiting a substantially symmetrical protruding shape (mound shape) with the position of the transmitting substrate **19** as a center thereof in the Z-axis direction occurs. As an example, when the transmission type radiation generating tube **11** is driven with an output of around 150 W, the external surface of the shield **20** can be presumed to have a highest temperature of 200° C. or higher.

A case where the transmitting substrate **19** is arranged at a position on the outer side relative to the external wall surface of the envelope **14** like in the present embodiment, and a case where the transmitting substrate **19** is arranged inside the external wall surface of the envelope **14** will be compared. Since the target **18** is mounted on the surface on the electron emitting source side of the transmitting substrate **19**, a part on the electron emitting source side relative to the transmitting substrate **19** has a high temperature. Accordingly, according to the present embodiment, the high-temperature part on the electron emitting source side relative to the transmitting substrate **19** contacts the cooling medium **33** via the shield **20**, and thus, the area for radiating heat to the cooling medium **33** is large relative to the case where the transmitting substrate **19** is arranged inside the envelope **14**.

More specifically, for the shield **20** in FIG. **1**, it is assumed that the length from an external surface of the transmitting substrate **19** to an extremity of the shield **20** is a (mm) and the length from the external surface of the transmitting substrate **19** to the external wall of the envelope **14** is b (mm). An increase in the amount of heat radiation from the shield **20** to the cooling medium **33**, which corresponds to the amount of the increase in the area where the shield **20** contacts the cooling medium **33**, is made compared to the case where the transmitting substrate **19** is arranged inside the external wall surface of the envelope **14**. Accordingly, the shield **20**'s cooling capability is increased around (a+b)/a times, enabling suppression of an increase in temperature of the target **18** and the transmitting substrate **19**.

As described above, the radiation generating apparatus **1** according to the present embodiment can provide a structure in which a large area is provided for radiating heat to the cooling medium **33** and a part having a highest temperature serves as a heat radiation surface, and thus, can provide a structure with a high heat radiation capability.

Accordingly, an increase in temperature of the target **18** and the transmitting substrate **19** per unit time during the transmission type radiation generating tube **11** being driven becomes smaller, and thus, it takes longer time for the target **18** and the transmitting substrate **19** to reach their respective upper temperature limits during the driving. Consequently, a radiation generating apparatus **1** using a highly-reliable transmission type radiation generating tube **11** enabling long-time driving for X-ray generation can be provided.

## Second Embodiment

Next, a radiation generating apparatus according to a second embodiment of the present invention will be described with reference to FIG. **2**. FIG. **2** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to the present embodiment, and a temperature distribution diagram at an external surface of a shield. For a description of components that are the same as those of the radiation generating apparatus **1** according to the first embodiment, reference numerals that are the same as those of the first embodiment are used.

As illustrated in FIG. **2**, a radiation generating apparatus **2** according to the present embodiment is different from the first embodiment in that a transmitting substrate **19** is arranged on a plane not perpendicular to, but inclined with regard to a passage **20***a* of a shield **20**. More specifically, a substrate inclination angle **24** corresponding to an angle formed by an electron flux center line **22**, which is a center line of an electron flux **17**, and a target-mounting surface of the transmitting substrate **19** (substrate surface direction **23**, which is an extension of an internal surface of the transmitting substrate **19**) is less than 90 degrees, and preferably, in the range of no less than 8 degrees to less than 90 degrees. If the inclination angle is less than 8 degrees, the length of the transmitting substrate **19** is large, which is impractical for a transmission type radiation generating tube **21**. In the case where the target substrate **19** is joined at an angle to the shield **20**, a surface of the joint has an oval ring shape, increasing the area of the joint, and thus, increasing the amount of heat transfer from the target substrate **19** to the shield plate **20**.

Next, an operation when the radiation generating apparatus **2** according to the present embodiment is driven will be described with reference to the temperature distribution diagram in the upper part of FIG. **2**. When the transmission type radiation generating tube **21** in the radiation generating apparatus **2** according to the present embodiment is driven, a temperature distribution with a protruding shape (mound shape) with a position of the transmitting substrate **19** as a center thereof occurs on an external surface of the shield **20** in a Z-axis direction. Since the transmitting substrate **19** is joined at an angle to the passage **20***a* of the shield **20**, an apex portion of the temperature distribution having a protruding shape with the position of the transmitting substrate **19** as a center thereof extends in an oval shape in a circumference direction of the shield **20**.

In the example in FIG. **2**, the temperature distribution of the external surface of the shield **20** exhibits that an upper portion of the surface and a lower portion of the surface are different from each other in highest temperature position in the Z-axis direction. Here, it is assumed that a distance from an intersection between the electron flux center line **22** and the target-mounting surface of the transmitting substrate **19** to an extremity of the shield is C (mm) and a distance from the intersection between the electron flux center line **22** and the target-mounting surface of the transmitting substrate **19** to the external surface of the envelope **14** is D (mm). Considering the temperature distribution of the entire circumference of the shield **20**, the effect of an increase in the amount of heat radiation to the cooling medium **33**, which substantially corresponds to an increase in the area where the shield **20** contacts the cooling medium **33**, is provided compared to a case where the transmitting substrate **19** is arranged inside the envelope **14**. Accordingly, the shield **20**'s cooling capability is increased by approximately (C+D)/C, enabling further suppression of an increase in temperature of the target **18** and the transmitting substrate **19** during X-ray generation.

As described above, the radiation generating apparatus **2** according to the present embodiment basically provides operations and effects similar to those of the first embodiment. In particular, in the radiation generating apparatus **2** according to the present embodiment, the transmitting substrate **19** is inclined, increasing the area where the transmitting substrate **19** contacts the cooling medium **33**, and thus, increasing the amount of heat radiated by the transmitting substrate **19** to the cooling medium **33**. Accordingly, the increase in temperature of the target **18** and the transmitting substrate **19** can further be suppressed.

## Third Embodiment

Next, a third embodiment of a radiation generating apparatus according to the present invention will be described with reference to FIG. **3**. FIG. **3** illustrates a schematic cross-sectional diagram of a radiation generating apparatus using a transmission type radiation generating tube according to the present embodiment, and a temperature distribution diagram at an external surface of a shield. The description will be provided using reference numerals that are the same as those of the radiation generating apparatus **1** according to the first embodiment for components that are the same as those of the first embodiment.

As illustrated in FIG. **3**, the radiation generating apparatus **3** according to the present embodiment is different from the first embodiment in that a cooling medium guiding portion **32** for guiding a cooling medium **33** into a shield **20** is provided. The cooling medium guiding portion **32** can be arranged at a position on the electron emitting source side relative to the transmitting substrate **19** so that the cooling medium **33** contacts a high temperature part of the shield **20**. More specifically, a groove-like cooling medium guiding portion **32** is formed at a position around the entire circumference of an external surface of the shield **20** where the external surface temperature is the highest, in the vicinity of a plane that is the same as that of the transmitting substrate **19**. A part of the shield **20** between a bottom portion of the cooling medium guiding portion **32** and the transmitting substrate **19** can be set to have a thickness of 2 mm or more. This is because such thickness is a lower limit thickness proper for X-rays generated in a target **18** and emitted in all directions to be shielded by the shield **20** to prevent operation staff for the radiation generating apparatus **3** from being exposed to radiation. If the thickness is less than 2 mm, it may be necessary to provide a structure having an X-ray shielding function outside the holding container **12**.

Next, an operation when the radiation generating apparatus **3** according to the present embodiment is driven will be described with reference to the temperature distribution diagram in the upper part of FIG. **3**. When the transmission type radiation generating tube **31** in the radiation generating apparatus **3** according to the present embodiment is driven, a temperature distribution having a substantially symmetrical protruding shape (mound shape) with a position of the transmitting substrate **19** as a center thereof occurs at the external surface of the shield **20** in a Z-axis direction. In the case where the transmission type radiation generating tube **31** is driven with power of around 150 W as an example, it can be presumed that the highest temperature of the external surface of the shield **20** is 200° C. or higher. As described above, in the case where the transmitting substrate **19** is arranged at a position on the outer side relative to an external wall of the envelope **14**, a high-temperature part on the electron emitting source side relative to the transmitting substrate **19** contacts the cooling medium **33**, and the area for heat radiation can be increased, compared to a case where the transmitting substrate **19** is arranged inside the envelope **14**. Consequently, an increase in temperature of the target **18** and the transmitting substrate **19** during X-ray generation can further be suppressed.

As described above, the radiation generating apparatus **3** according to the present embodiment basically provides operations and effects similar to those of the first embodiment. In particular, in the radiation generating apparatus **3** according to the present embodiment, a groove-like cooling medium guiding portion **32** is formed at the external surface of the shield **20**, allowing the cooling medium **33** to enter the cooling medium guiding portion **32**, and thus, increasing the area of contact between the cooling medium **33** and the shield **20**. Consequently, an increase in temperature of the target **18** and the transmitting substrate **19** can further be suppressed.

## Fourth Embodiment

Next, a radiation imaging apparatus according to a fourth embodiment using a radiation generating apparatus described above will be described with reference to FIG. **4**. FIG. **4** is a schematic diagram illustrating a radiation imaging apparatus according to the present embodiment. Here, the radiation generating apparatus **1** in FIG. **1** is used; however, an X-ray imaging apparatus can be provided using the radiation generating apparatus **2** in FIG. **2** or the radiation generating apparatus **3** in FIG. **3**. Accordingly, in FIG. **4**, only reference numerals for the radiation generating apparatus **1** according to the first embodiment are provided.

As illustrated in FIG. **4**, a radiation imaging apparatus **4** according to the present embodiment is configured so that a radiation detecting unit (X-ray detector) **41** is arranged ahead in a direction of X-ray emission of a transmission type radiation generating tube **11** via a non-illustrated object.

The X-ray detector **41** is connected to an X-ray imaging apparatus control unit **43** via a signal processing unit (X-ray detection signal processing unit) **42**. Output signals from the

X-ray imaging apparatus control unit **43** are connected to respective terminals on the electron emitting source side of the transmission type radiation generating tube **11** via an electron emitting source drive unit **44**, an electron emitting source heater control unit **45** and a control electrode voltage control unit **46**. Also, an output signal from the X-ray imaging apparatus control unit **43** is connected to a terminal of a target **18** in the transmission type radiation generating tube **11** via a target voltage control unit **47**.

Upon generation of X-rays in the transmission type radiation generating tube **11** in the radiation generating apparatus **1**, radiations in the X-rays emitted to the air that has penetrated an object is detected by the radiation detecting unit **41**, and the signal processing unit **42** forms a radiographic image (X-ray radiographic image) from the result of detection by the radiation detecting unit **41**.

The radiation imaging apparatus **4** according to the present embodiment uses the radiation generating apparatus **1** using the highly-reliable transmission type radiation generating tube **11** enabling long-time driving for X-ray generation, and thus, a highly-reliable X-ray imaging apparatus enabling long-time driving for X-ray generation can be provided.

Although exemplary embodiments of the present invention have been described above, these embodiments are mere examples for describing the present invention, and the present invention can be carried out in various modes different from the embodiments as long as such modes do not depart from the scope and spirit of the present invention.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2010-275620, filed Dec. 10, 2010, which is hereby incorporated by reference herein in its entirety.

The invention claimed is:

**1**. An X-ray radiation generating apparatus comprising:
an X-ray radiation generating tube having
an envelope having an aperture,
an electron emitting source arranged in said envelope,
a target arranged in opposition to said electron emitting source and generating X-ray radiation responsive to an irradiation with an electron beam emitted from said electron emitting source, and
a tubular shield member shielding a part of the X-ray radiation emitted from said target and including an inner wall defining an electron beam pass; and
a holding container holding said X-ray radiation generating tube inside said holding container,
wherein said tubular shield member is provided in said aperture so as to protrude toward an outside of said envelope so that said target is held at an outer side of said envelope beyond said aperture, and
wherein said target is held at said inner wall of said tubular shield member such that said target and said inner wall of said tubular shield member meet at an angle that is not a right angle.

**2**. The X-ray radiation generating apparatus according to claim **1**, wherein said target has a target thin film arranged in a side so as to face said electron emitting source, and has a supporting substrate arranged at an opposite side of said target thin film, for supporting said target thin film.

**3**. The X-ray radiation generating apparatus according to claim **2**, wherein said supporting substrate is formed from diamond.

**4**. The X-ray radiation generating apparatus according to claim **1**, wherein said target is arranged with a normal axis of said target inclined at an angle with regard to a direction of the electron irradiation.

**5**. The X-ray radiation generating apparatus according to claim **1**, further comprising:
a cooling medium positioned between said holding container and said X-ray radiation generating tube,
wherein said cooling medium contacts at least a part of a protruding portion of said tubular shield member.

**6**. The X-ray radiation generating apparatus according to claim **5**, wherein said cooling medium is an electric insulating oil or a fluorochemical inactive liquid.

**7**. The X-ray radiation generating apparatus according to claim **6**, wherein said cooling medium is an electric insulating oil, and said electric insulating oil is a silicone oil or a fluorochemical oil.

**8**. An X-ray radiation imaging apparatus comprising:
an X-ray radiation generating apparatus according to claim **1**;
an X-ray radiation detecting unit for detecting X-ray radiation generated by said X-ray radiation generating apparatus and transmitted through an object; and
a signal processing unit for forming a transmitted-radiation image based on a result of detection by said X-ray radiation detecting unit.

**9**. An X-ray radiation generating apparatus comprising:
an X-ray radiation generating tube having
an envelope having an aperture,
an electron emitting source arranged in said envelope,
a target arranged in opposition to said electron emitting source and generating X-ray radiation responsive to an irradiation with an electron beam emitted from said electron emitting source, and
a tubular shield member shielding a part of the X-ray radiation emitted from said target and including said inner wall defining an electron beam pass; and
a holding container holding said X-ray radiation generating tube inside said holding container,
wherein said tubular shield member is provided in said aperture so as to protrude toward an outside of said envelope so that said target is held at an outer side of said envelope beyond said aperture, and
said target is held on said inner wall of said shield member inclined at an angle to said inner wall of said shield member such that an area over which said target and said inner wall are in contact is larger than would be the case if said target were at a right angle to said inner wall.

**10**. The X-ray radiation generating apparatus according to claim **9**, further comprising:
a cooling medium positioned between said holding container and said X-ray radiation generating tube,
wherein said cooling medium contacts at least a part of a protruding portion of said tubular shield member.

**11**. The X-ray radiation generating apparatus according to claim **9**, wherein said target has a target thin film arranged facing said electron emitting source, and has a supporting substrate arranged at a side opposite to said target thin film, for supporting said target thin film.

**12**. The X-ray radiation generating apparatus according to claim **11**, wherein said supporting substrate is formed from diamond.

**13**. The X-ray radiation generating apparatus according to claim **9**, wherein said target is arranged with its normal axis inclined at an angle relative to a direction of propagation of the electron irradiation.

**14**. The X-ray radiation generating apparatus according to claim **9**, wherein said cooling medium is an electric insulating oil or a fluorochemical inactive liquid.

**15**. The X-ray radiation generating apparatus according to claim **14**, wherein said electric insulating oil is a silicone oil or a fluorochemical oil.

**16**. An X-ray radiation imaging apparatus comprising:

an X-ray radiation generating apparatus according to claim **9**;

an X-ray radiation detecting unit for detecting X-ray radiation generated by said X-ray radiation generating apparatus and transmitted through an object; and

a signal processing unit for forming an X-ray radiation transmitting image based on a result of detection by said X-ray radiation detecting unit.

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